

P-Adaptivity in Digital Image Correlation

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1. INTRODUCTION

The DIC technique has been widely used in experimental mechanics due to its low experimental cost such as simple setup, simple specimen preparation and low requirements in measurement environment. The traditional approach is a subset based approach, having some important drawbacks, keeping it from being used in some specific domains. The lack of inter-subset continuity increases sensitivity of the local approach against noise, leading to noisy measured displacements. These measurements should be smoothed out prior to differentiation to minimize their effects on the strain. The downside of this method is that the choice of subset, step and strain window influences the spatial resolution and thus makes data very user dependent. For this reason measuring a high gradient strain field with small amplitudes is difficult using subset based DIC. To avoid the non-continuous displacement field, several global approaches were presented. The current implementations of these global approaches all use a fixed degree of freedoms (DOF), ranging from lower (Q4 element) to higher order (24 node elements) meshes. The use of fixed DOF leads to very user/approach dependent results, as natural smoothing is performed. Here, to circumvent this dependency a self-adapting global DIC procedure is proposed. The main topic discussed is the algorithm itself.

2. CONCEPT

The self-adapting procedure is based on conservation of optical flow. By minimizing the sum of squared differences (1) with respect to the displacement parameters used in the displacement description (2), a linear system (3) is obtained.

$$\epsilon^2 = \iint_{\Omega_e} (f(x+d) - g(x+d'))^2 dx \quad (1) \quad d = \sum_i \sum_{\alpha} \Phi_i(x) d_{i\alpha} \quad (2)$$

$$\rightarrow K^S \cdot d = F^S \quad (3)$$

Where $f(x)$ and $g(x)$ are respectively the reference and deformed image, d the displacement described by the shape functions $\Phi_i(x)$ and displacement parameters $d_{i\alpha}$. The choice of shape functions defines the number of DOF's, and thus the order/polynomial degree of the elements used (e.g. Q4, Q8 elements). Other than in the current approaches, the DOF are not fixed in the self-adaptive approach. By using error/convergence estimators, the algorithm adapts/updates the mesh where needed (e.g. regions with highly heterogeneous deformation) in analogy with adaptive finite element procedures. By using hierarchical shape functions, updating the mesh can be done very efficiently without changing the geometry and number of elements. Adding extra DOF's only leads to expanding the linear system with extra parameters and coefficients regarding the newly introduced DOF. For example, updating a mesh from n to n' DOF (adding m DOF) leads to following linear system:

$$K^{n'} \cdot d_{n'} = F^{n'}$$

with:

$$[K^{n'}] = \begin{bmatrix} K^n & K^m \\ K^m & K^{mm} \end{bmatrix} \text{ and } [F^{n'}] = \begin{bmatrix} F^n \\ F^m \end{bmatrix}$$

This way of updating is analogous to p-refinement in FEA, as each region gets extra DOF (higher order functions) when updated. By using the p-refinement, the self-adaptive procedure independently determines which DOF is needed to describe the deformed surface based on the error/convergence estimators. As a consequence, homogenous deformation will require lower order shape functions, while - in contrast - heterogeneous regions will require higher order shape functions. The estimators are based on displacement and strain norms, much like the ones used in p-methods in FEA. The new method is called p-DIC. A simple flowchart of the newly proposed method is shown in Fig 1.

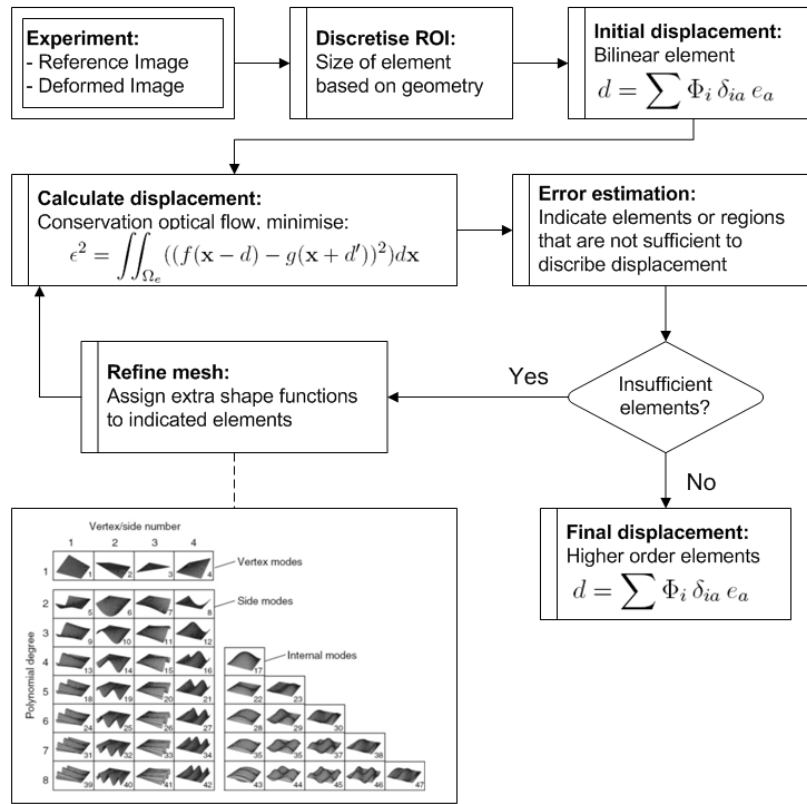


Fig 1: Flowchart of the p-DIC algorithm.

3. ADAPTIVITY

The concept of the new method, p-DIC, is shown on an numerical deformed image. The displacement imposed is a horizontal sinusoidal deformation field. The frequency of the sine wave increases from left to right, resulting in an image with a variation in needed spatial resolution. The correlation is performed with several sizes of meshes. As the frequency rises from left to right, also the order of elements should rise from left to right. Changing element size, will influence the element order in a similar way. Larger elements need higher orders than small elements. The order distribution for 3 different sizes of mesh is shown in fig 2.

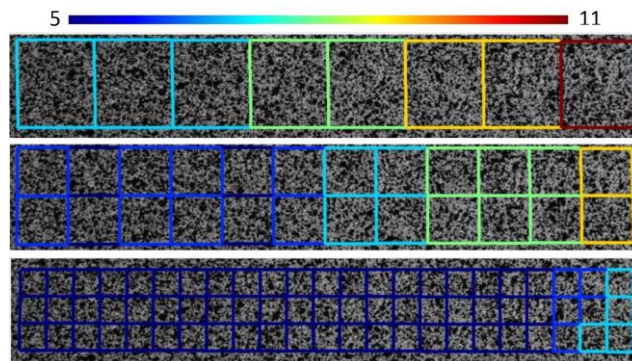


Fig 2: Distribution element orders for changing spatial resolution and element size.

For traditional DIC, the correlation parameters (subset, step, strain window) will heavily change the data. The p-DIC method is, due to the self-adapting feature, less influenced by the user input (mesh size) and thus maintain accuracy. The spatial resolution is, in comparison to the local method, not limited by initial user settings.

4. APPLICATION

As application, a tensile test is numerically simulated. A holed aluminum specimen is used, producing a heterogeneous strain field. The images are correlated using an arbitrary first order mesh with element size 100 pixels. Because of the adaptive procedure, element orders will be increased if needed. In fig 3, the reference image, deformed images and final element order distribution is shown.

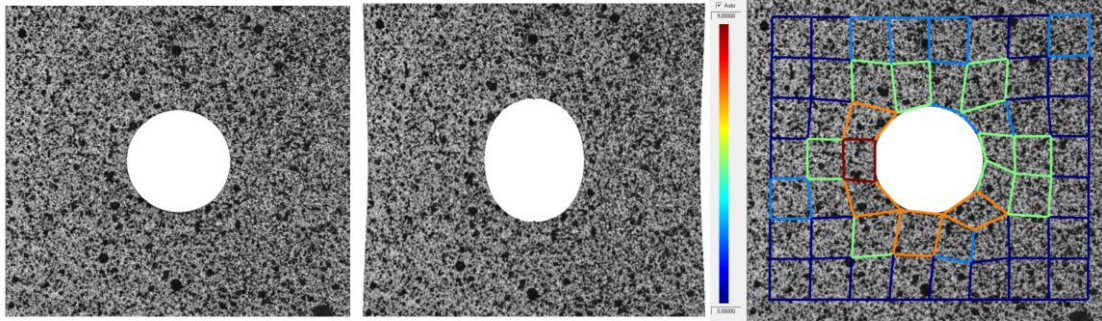


Fig 3: Reference image, deformed image and element order distribution

Regions around the hole will produce more heterogeneous deformations, resulting in higher order elements. Correlating the same images with different mesh sizes barely influence final results, proving the concept of p-DIC. The error of displacement for the subset method and p-DIC method is shown in fig 4.

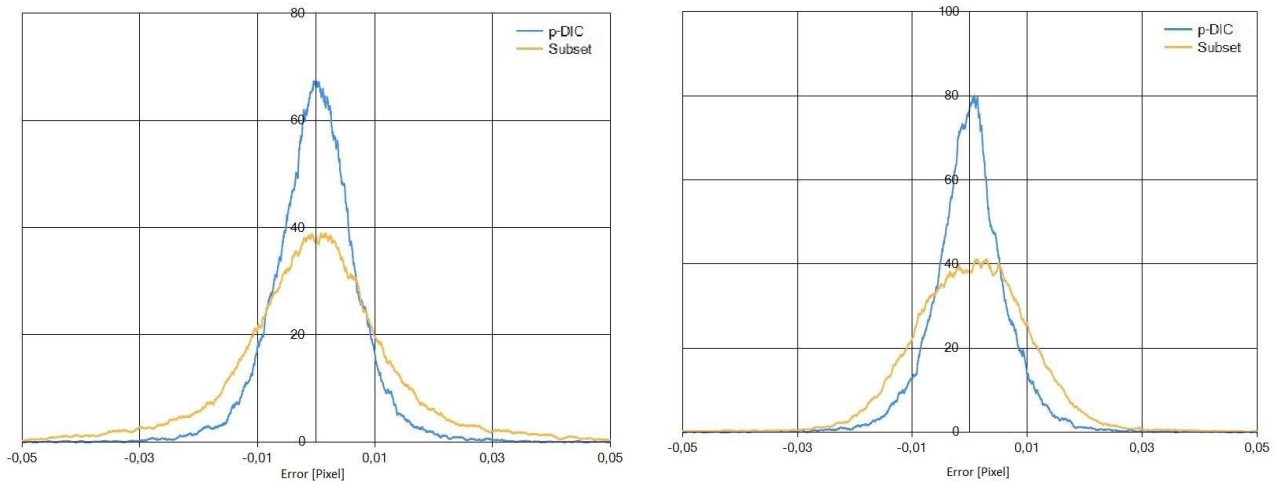


Fig 4: Error distribution horizontal and vertical displacement for subset and p-DIC method.

4. CONCLUSION

A new correlation algorithm is presented. The algorithm is based on global digital image correlation and adopts features from the adaptive finite element. The region of interest is described by an adaptive element mesh. A p-refinement scheme is implemented so that the elements in the mesh are capable of rising (automatically) in DOF when the error estimators indicate them to do so. Using a numerical simulated test, a comparison of the traditional local and newly presented p-DIC is performed. Results from the comparison indicate that the p-DIC method has a smaller distribution of error compared to the local method. Besides the advantage in performance at optimal settings, another big advantage is found. Because of the self-adapting mesh, the method becomes less user dependent. The spatial resolution is, in comparison to the local method, not limited by initial user settings. Also measurements can go until the edges and an error indication can be provided. In other work, an in depth validation of the method is performed. Future work is mainly aimed at the further development of the error estimators as they are a key in the p-DIC procedure.